

ON SEDIMENT-INDUCED PROBLEMS UNDER THE DAM REHABILITATION AND IMPROVEMENT PROJECT IN INDIA

BY SANJAY GIRI AND PRAMOD NARAYAN

Reservoir sedimentation in India

Dams and reservoirs are important assets in India with strong seasonal flow pattern variations and highly increasing water and energy demands due to rapid growth of economy and population. The negative impacts of dams and reservoirs can be attributed to poor planning, mismanagement, inefficient operations and insufficient consideration (or negligence) of mitigation strategies. The importance of dams and reservoirs and both their positive and negative impacts should be objectively measured vis-a-vis multi-sectorial benefits, specific priorities and demands.

India has 5,262 completed large dams, of which 2,329 were commissioned before 1980 and 437 dams are currently under construction. The loss of storage capacity in these reservoirs has become one of the major concerns for water security and structural safety. For comparison's sake, reservoir sedimentation studies of 243 dams in India¹ have revealed that about 26 billion m³ of gross storage volume has already been lost, which is more than the total storage capacity (about 23 billion m³) of all large dams in Japan. Figure 1 shows the gross storage losses in selected reservoirs in eight Indian states. To review the actual sedimentation in some relevant reservoirs, a plan scheme has been initiated by the Ministry of Water Resources, River Development and Ganga Rejuvenation to conduct surveys on a regular basis.

Dam safety and rehabilitation efforts in India

Construction of new dams and reservoirs has become more difficult due to increasing social, environmental, resettlement and rehabilitation constraints and compliances. In most cases, the water stress situation in several states of India can be attributed to improper management of available resources and infrastructure like dams and canals. Consequently, dam rehabilitation and improvement efforts have become indispensable. The Central Dam Safety Organization (CDSO) of the Central Water Commission

(CWC) encourages and facilitates dam safety and rehabilitation practices in India. A Dam Rehabilitation and Improvement Project (DRIP) (www.damsafety.in) was initiated by the Government of India in 2012 with the assistance of the World Bank as a continuation of the previous Dam Safety Assurance and Rehabilitation Project (DSARP). The primary objective of DRIP is to improve the safety and operational performance of about 250 dams in seven states of India along with strengthening institutional capacity and promoting sustainable dam management, not only at the central level,

but also in participating states and agencies. Initially, sediment-induced problems were not identified as a priority within DRIP. However, growing concerns lead different dam authorities in the states to explore sediment management strategies for some reservoirs. These reservoirs are not only losing storage capacity, but also suffering from abrasion, clogging and malfunctioning of civil structures, such as weirs, spillways, desilting basins, stilling basins, roller buckets, under-slucices, guide banks (Figure 2), mechanical and electrical equipment and apparatus (e.g. turbines, gates, trash racks). Priority has been given to rapid assessment and handling of sediment-induced problems in few selected reservoirs. A handbook is being prepared synthesizing past and on-going experiences, technologies, existing research, case studies and practices related to a broad spectrum of sediment-induced problems in reservoirs. The handbook shall provide guidance on how to assess and manage/ combat reservoir sedimentation.

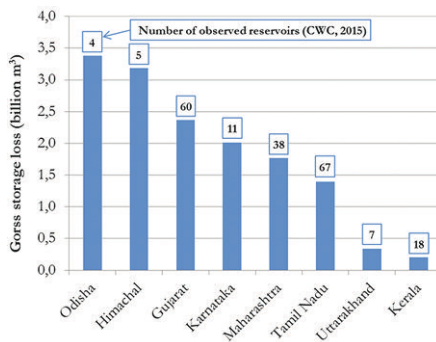


Figure 1. Reservoir gross storage loss in some states of India (based on data of CWC¹)

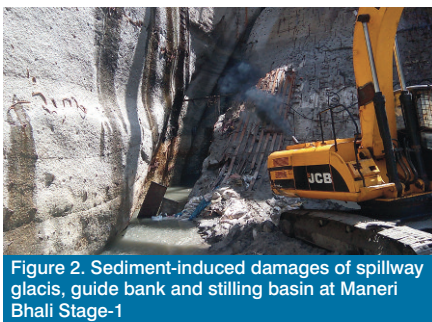


Figure 2. Sediment-induced damages of spillway glacis, guide bank and stilling basin at Maneri Bhali Stage-1

Rapid assessment and handling considering beneficial reuse

Based on requests from the state dam authorities, five reservoirs have been selected for rapid assessment of sediment-induced problems, namely the Kundah Palam, Pillur and Papanasam reservoirs in Tamil Nadu State (located in sedimentation zone of south part of India, characterized by Deccan Plateau^[1]), and the Maneri Bhali Stage-1 and Dakpathar barrage in Uttarakhand State (located in the sedimentation zone of the north part of India, characterized by Himalayan Region and Indo-Gangetic Plains^[1]). In addition, a pilot study is being carried out for the Dakpathar barrage, supported by the Dutch Partners for Water (PvW) Programme.

Rapid assessment and analyses were made based on field reconnaissance, some old data and information that were readily available. Results for some of these reservoirs are summarised in Table 1, including sources of the problems and sediment handling options based

Table 1. Sediment-induced problems, their sources, preliminary selection of sediment handling and beneficial reuse options in selected reservoirs under DRIP

Dam (Type)	Gross storage	Sediment Zone ¹	Purpose	Problems	Sources/Reasons	Sediment Handling/Reuse Options
Kundah Palam (Forebay)	1.76 million m ³	Deccan Plateau	Hydropower	<ul style="list-style-type: none"> Storage loss (≈60%) Partially clogged scour vent and trash rack at tunnel intake, leading to risk of failures and disruption in power generation (Figure 4) 	Surface erosion, erosion of bare lands (due to cultivation on slopes without terrace), mud, fine sediment (not harmful for turbines)	<ul style="list-style-type: none"> Phase-wise sediment removal plan in three reaches (divided based on morphological feature) to minimize hindrance to power generation^[2] Dry excavation in upstream reaches, trucking and dumping^[2] Hydraulic dredging (syphoning/pumping) near dam area and partly downstream release^[2] Sediment measurement and monitoring (Reservoir Morphology Information System) Regular sluicing during monsoon <p>Sediment reuse options</p> <ul style="list-style-type: none"> Land improvement by filling a valley-like area, owned by dam authority, and develop it as a playground or recreational park^[2] Top soil enhancement for agricultural land Sediment trap upstream (by simply keeping intact a part of consolidated deposition in form of a spur) Downstream morphological and ecological enhancement by controlled release of deposited material
Pillur (Storage)	34.97 million m ³	Deccan Plateau	Hydropower Water supply	<ul style="list-style-type: none"> Storage loss (≈42%; ≈ 20 million m³ of deposition) Increasing sedimentation near water supply intake Clogged under-sluices Sediment consolidation 	Surface erosion, erosion of bare lands (cultivation on slopes without terrace), mud, fine sediment (not harmful for turbines)	<ul style="list-style-type: none"> Regular maintenance using hydraulic dredging (syphoning or pumping)^[3] Downstream release and replenishment^[3] Regular sediment removal (recurrent measure) from key locations (e.g. near water supply intake, hydropower intake, under-sluices) Proper study and measurement to avoid downstream impacts Investigation of sediment bypass system Sediment measurement and monitoring (Reservoir Morphology Information System) Regular sluicing/venting during monsoon <p>Sediment reuse options</p> <ul style="list-style-type: none"> Land improvement and agricultural enhancement Construction material Enhancement of downstream river environment
Maneri Bhai Stage-1 (Run-of-the-River)	0.6 million m ³	Himalayan Region	Hydropower	<ul style="list-style-type: none"> Abrasion and damage of spillway, gates, stilling basin, guide banks/walls (Figure 2) Large deposition (up to spillway crest, Figure 4) Migrating sediment delta 	River erosion, landslides, debris flow, road construction, graded materials, fine silt (like quartz, harmful for turbines)	<ul style="list-style-type: none"> Sediment removal by dry dredging and trucking (removing sediment in front of the spillway provides favorable condition to minimize damages of spillway and gates due to the trapping of gravels and boulders^[4]) Regular maintenance using hydraulic dredging (pumping or syphoning) Soft and temporary sediment trap upstream of the reservoir (also to assess the transport^[4]) Improved gate operation during high flows and sluicing^[4] Monitoring and forecasting systems <p>Sediment reuse options</p> <ul style="list-style-type: none"> Construction materials for river and other infrastructure Soft structural and recurrent measures (geotubes, gabions) to trap sediment
Dakpathar (Barrage, forebay)	0.71 million m ³	Indo- Gangetic Plain	Hydropower Irrigation Recreation	<ul style="list-style-type: none"> Storage loss Unfavorable sediment deposition in power intake area 	River erosion, landslides, debris flow, large materials, fine silt (like quartz, harmful for turbines)	<ul style="list-style-type: none"> Intelligent dredging (pumping) and dumping within reservoir considering morphological features, location of power channel intake and gates Regular maintenance using hydraulic dredging (pumping or syphoning) Regular and intelligent sluicing Improved gate operation Monitoring and forecasting systems <p>Sediment reuse options</p> <ul style="list-style-type: none"> Filling geotubes to be used as baffle and traps for improving morphological condition in the reservoir Construction materials for using within (for bank protection) and outside the reservoir Improving environmental conditions for migrating birds and habitats

on a quick assessment of technical, economic and environmental feasibility and impacts^[2,3,4]. Emphasis is given to beneficial reuse of the deposited material as a potential resource and not as a waste, supporting therefore the circular economy concept (Figure 3). Variability in type, magnitude and sources of

sediment-induced problems reveals their complexity and distinctiveness, indicating the need for a tailor-made approach to each individual dam. It should be mentioned that reservoir sedimentation problems in the southern reservoirs (Tamil Nadu State) are not always due to high erosion rate in upper catch-

ments, but rather to unprofessional dam operations and lack of regular sediment handling measures. There are provisions of addressing sediment problems, but they are usually ignored by hydropower entities and water resources authorities, particularly in water stressed areas. Therefore, a judicious trade-off is essential to



Figure 3. Sediment reuse concept for circular benefit

address these problems holistically. It is recommended that proper measurements and detailed analyses be carried out to fine-tune the proposed options of sediment handling.

Constraints

Complexity and constraints, associated with reservoir sediment management in India, are related not only to techno-economic feasibility, but also to social, environmental and legal aspects. Major constraints include social and environmental impacts of sediment removal, transport and disposal options, the presence of preserved areas and sanctuaries in the vicinity of reservoirs, and the consolidation and contamination of the deposited materials. There are several legal and institutional constraints, such as ambiguous regulations for sediment removal and disposal from reservoirs, inefficient rules and decision-making processes for hydropower and multipurpose reservoir operations, and inter-state disputes on the operation and management of transboundary reservoirs. Reservoirs located in reserved forest areas are

governed by different rules and regulations, ultimately leading to unwarranted delays that impact adversely the overall implementation of rehabilitation projects. For such reservoirs, new set of rules and guidelines need to be established in order to have a balance between societal needs and environmental safeguard. Also, lack of relevant data and information create certain constraints to undertake sediment management.

Application of knowledge, tools and technology

For rapid assessment of impacts associated with sediment management options and alternatives (cf. Table 1) within DRIP and PWW programme, several methods, tools and technology have been applied^[2,3,4] such as (i) professional knowledge and local experience, (ii) morphological numerical modelling with Delft3D, coupled with Feedback Control Tool to simulate gate operation, (iii) sediment and bathymetry measurements (for Dakpathar pilot case), (iv) smart sediment dredging using

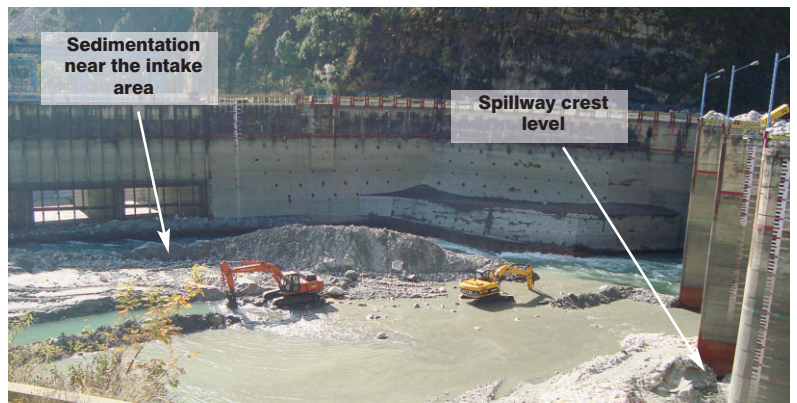



Figure 4. Sediment deposition at Kundah Palam in Tamil Nadu (left) and Maneri Bhali Stage-1 in Uttarakhand (right), revealing differences in source, feature and sedimentation rate



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Pramod Narayan is working with Central Water Commission for more than 22 years. Currently, he is the director of Dam Safety Rehabilitation Directorate and a project director for World Bank assisting ongoing Dam Rehabilitation and Improvement Project (DRIP) in India. He is also the nodal officer coordinating the DRIP activities with various international partners. He has worked as member secretary for various expert review panels and he has been one of the contributors publishing guidelines and manuals for dam safety management.

environmental friendly equipment, (v) application of innovative techniques for dewatering, treatment and reuse of dredged materials (sludge, mud, fine sand, gravels). It has been proposed to establish flow and sediment monitoring as well as inflow forecasting systems for all these reservoirs. For example, a Reservoir Morphology Information System (RMIS) has been described in the DRIP handbook. This handbook contains also materials about worldwide experiences and state-of-the-art approaches and technologies for the assessment and management of sediment-induced problems in reservoirs. These materials can serve as a knowledge base

to prepare tailored guidelines and procedures to assist dam owners to address reservoir sedimentation challenges systematically and holistically. Additionally, a tool for supporting decision-making processes, currently being developed, will be useful for selecting and prioritizing sediment management options^[5].

Failure examples and lessons learnt

Hereafter, two failure examples are given, serving as lessons to be considered while preparing and executing sediment management operations.

Sediment disaster at Pillur reservoir: An attempt was made to empty the Pillur reservoir in 1991 (after about 30 years of dam operation) through drawdown flushing, but ended in disaster. The deposited amount of sediment was huge for uncontrolled flushing through the under-sluices (scour vents)^{2,3}. The slurry was an hyper-concentrated fluidized sediment mass that did not behave like normal sediment-water mixture,

bursting toward the powerhouse (located downstream at the left side of the dam body). The powerhouse was covered with large amount of sediments and the generation had to be stopped for few months. Since then the under-sluices have never been used for sluicing or flushing, and apparently they have become clogged again.

Environmental havoc at Kallarkutty reservoir:

There was a serious environmental disaster caused by an uncontrolled reservoir flushing^[6] in this reservoir, located in the Pariyar River (Kerala State) in the downstream-most area of Mudirapuzha basin. Apparently, the area near the Pariyar River and its banks was polluted by industrial effluents⁶, contaminating reservoir sediment deposits. Sediment removal operations had not been carried out for more than 18 years regardless of the fact that there were provisions for regular sluicing⁶. Moreover, no proper investigation was carried out to assess quantity and quality of deposited materials. This

led to spreading of contaminated flushed sediment and water into several rural water supply pumping systems, located in downstream areas. The water supply system in the entire Kochi region as well as aquatic and habitat life in the downstream reach were severely affected^[6]. ■

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Professor Geoffrey Petts (1953-2018)

Geoffrey Petts was an outstanding scientist who made distinguished contributions to river science and, notwithstanding his move into university senior management in 2001 and becoming Vice-Chancellor and Rector of the University of Westminster, he continued to conduct research, supervise doctoral students and edit a major international journal. While his research profile is stunning, his personal qualities made him a particularly exceptional individual, explaining why so many people across the globe will miss him deeply.



Geoff was a larger-than-life character, who always maintained a positive attitude even during difficult times, facing life's challenges with endless good humour. He treated everyone equally, hearing and acknowledging people's views even if he did not agree with them. He was also prepared to make what he believed to be the right decisions, even when they might be unpopular. He was an exceptional leader, a great team player, an inspirational teacher and speaker, and a sincere, reliable friend.

Geoff's doctoral research focussed on the geomorphological response of river channels to flow regulation by dams. Unusually for the time, but typical of Geoff's interests throughout his academic career, this research tackled an important applied problem as well as delivering an excellent piece of fundamental science. Although starting as a geomorphologist, he soon recognised that river science needed to address the intimate linkages between geomorphology, hydrology and ecology. He was one of the first to recognise that multidisciplinary understanding was the key to developing sustainable solutions to river management problems.

Geoff published on numerous aspects of river science from physical to chemical and biological, from patch to catchment scales, and always with the aim of developing practical applications of the results. In adopting this holistic approach, he was adhering to the truly geographical (integrative, multi-scale) tradition to which he subscribed. Pursuing this tradition, his early research on

dams and geomorphology resulted in the publication in 1984 of his best known and scientifically revolutionary book 'Impounded Rivers', which, according to Google Scholar, has achieved over 1500 citations. Geoff authored and edited a further 21 books and the Web of Science lists 129 papers. He founded the journal *River Research and Applications* (previously *Regulated Rivers*), reflecting his multidisciplinary and applied interests in river research and management, and served as Editor in Chief from 1985 to 2016. These numerous and varied academic outputs are all the more remarkable considering that such a large part of his career was devoted to university management.

As well as publishing prolifically, Geoff supervised 22 research students. He also held many influential appointments related to river science including: Director of the International Water Resources Association; President of the International Society for River Science (2011-13); and President of the British Hydrological Society (2015-17). Among many awards, he received the Busk Medal from the Royal Geographical Society (2007) and a Lifetime Achievement Award from the International Society for River Science (2009).

Geoff made so many good friends across the globe. He spread good will internationally and was a magnificent ambassador for river science and its related disciplines of geography, geomorphology, hydrology and river ecology. He was also a family man, who stressed the important contribution of his parents in encouraging him to work hard and aim high. He is survived by his wife of over 40 years, Judith, who gave him enormous support throughout those decades. Geoff Petts - Vice Chancellor, Professor, scientist, teacher, mentor and friend - will be sorely missed by all of us.

Angela Gurnell
(based on an obituary written for the British Society for Geomorphology and the Royal Geographical Society)